Concept in optical transitions in bulk semiconductors-

- Absorption process
- Explanation for spontaneous emission-stimulated emission-transition rate
- Relation between Einstein’s coefficients

Absorption of Radiation:

When the atoms absorb energy by any means in the ground state, the electrons of the atom absorb energy and reach to higher energy level. Now the atom is said to be in excited state. Let us consider two energy levels 1 and 2 of an atom with energies E_1 and E_2. If the atom is initially in the lower energy state E_1, it can be raised to energy state E_2 by absorbing a photon of energy E_1-E_2=hν. This process is called **stimulated absorption**. Usually the number of excited particles (atoms) in the system is smaller than the non –excited particles. The time up-to which the particle can remain in excited state is known as life time. For Hydrogen atom, it is around 10^{-8} second.

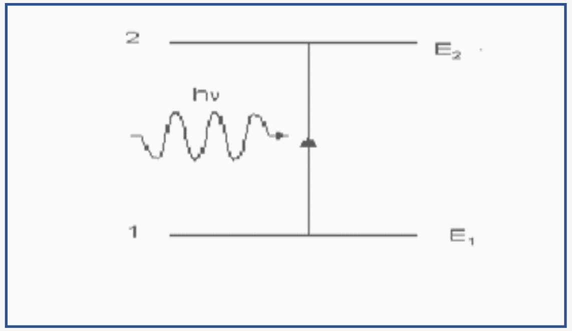


Fig1. Absorption phenomenon

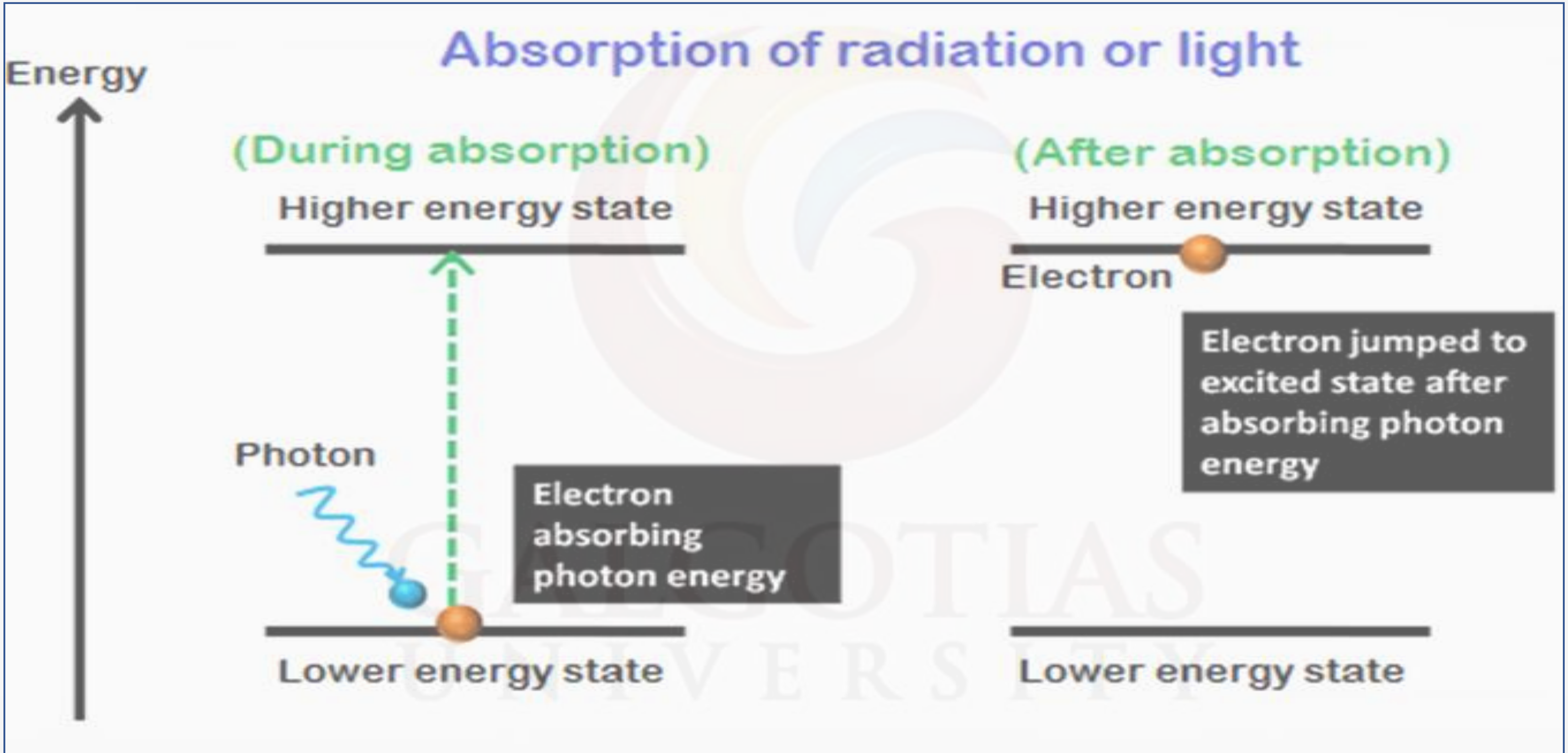


Fig1. Absorption phenomenon

Spontaneous emission of radiation

The excited state with higher energy E_2 is not a stable state. After a short interval of time, the atom jumps back to ground state by emitting a photon of frequency υ. This type of emission is called **spontaneous emission**.

The spontaneous emission is random in character. If there is an assembly of atoms, the radiation emitted spontaneously by each atom has a random direction and a random phase. Thus the radiation in this case is a random mixture of quanta having various wavelengths. Thus spontaneous emission is incoherent and has broad spectrum.

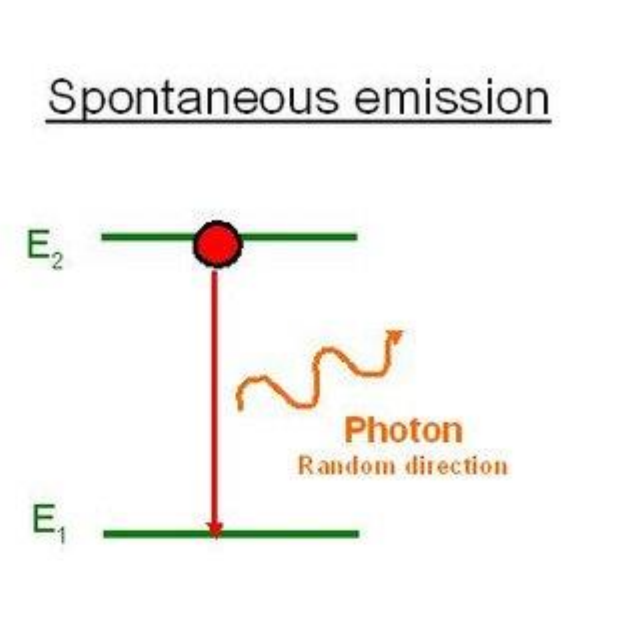


Fig2. Spontaneous emission

Spontaneous emission of radiation

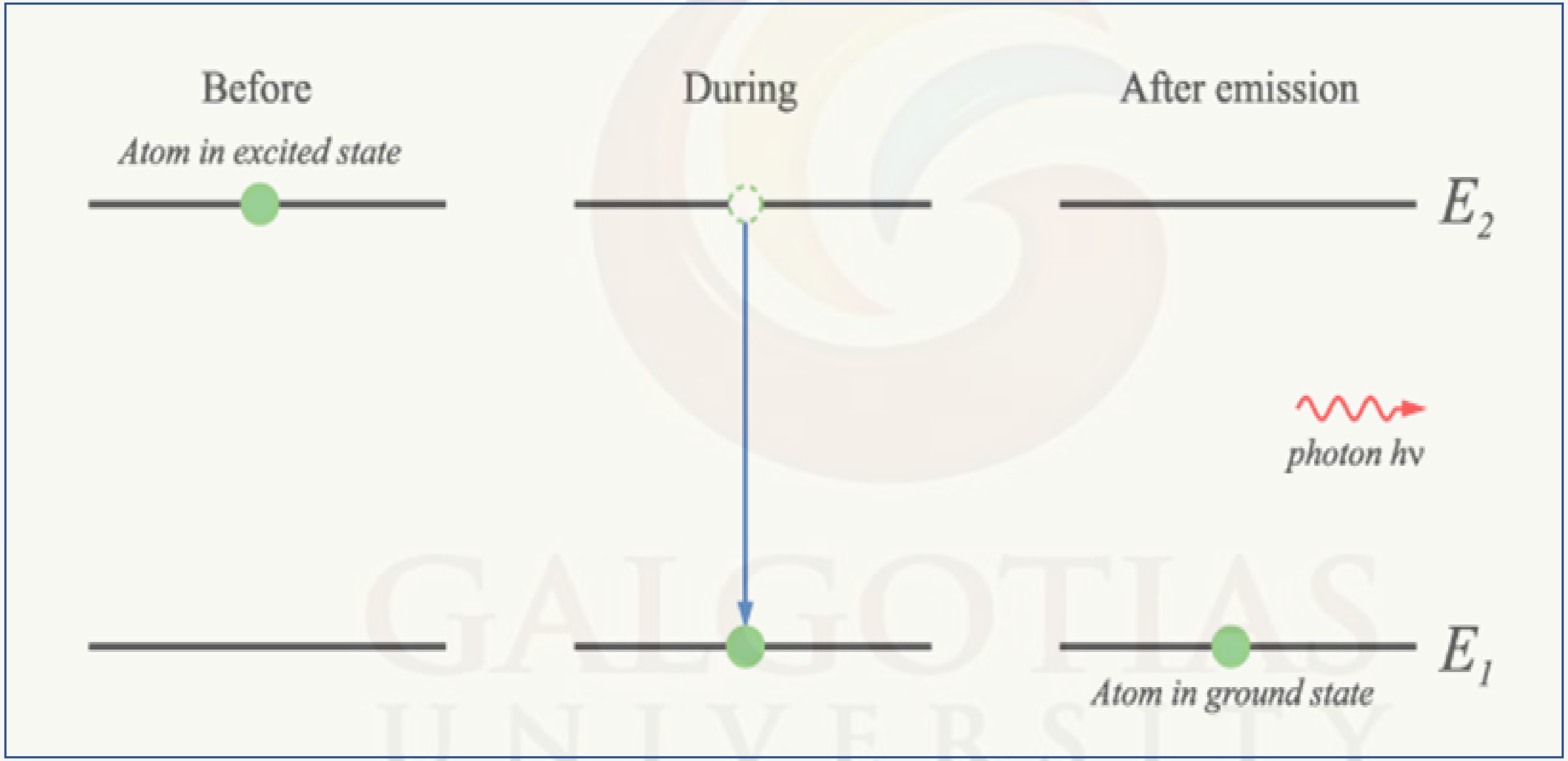


Fig2. Spontaneous emission

Stimulated (induced) emission of radiation

In 1917, Einstein proposed this kind of emission. In this phenomenon, an incident photon of energy hυ causes a transition from E_2 to E_1. So the radiated light emits an addition photon of same frequency υ. Hence two photon two photon move together. This phenomenon is called **stimulated emission of radiation.** The direction of propagation, phase and energy of the emitted photon is exactly same as that of incident photon. Thus result is an enhanced beam of coherence light. Emitted photons are in same state of polarization.

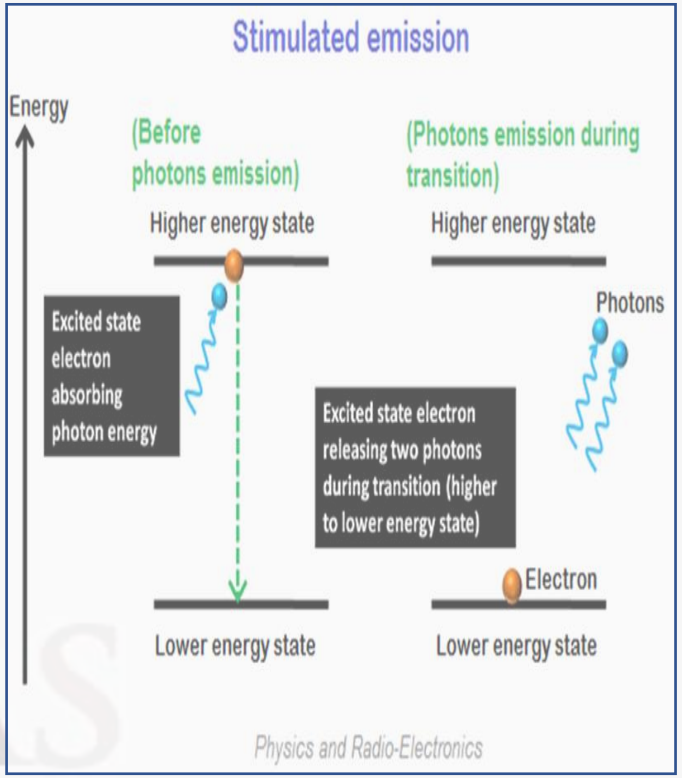
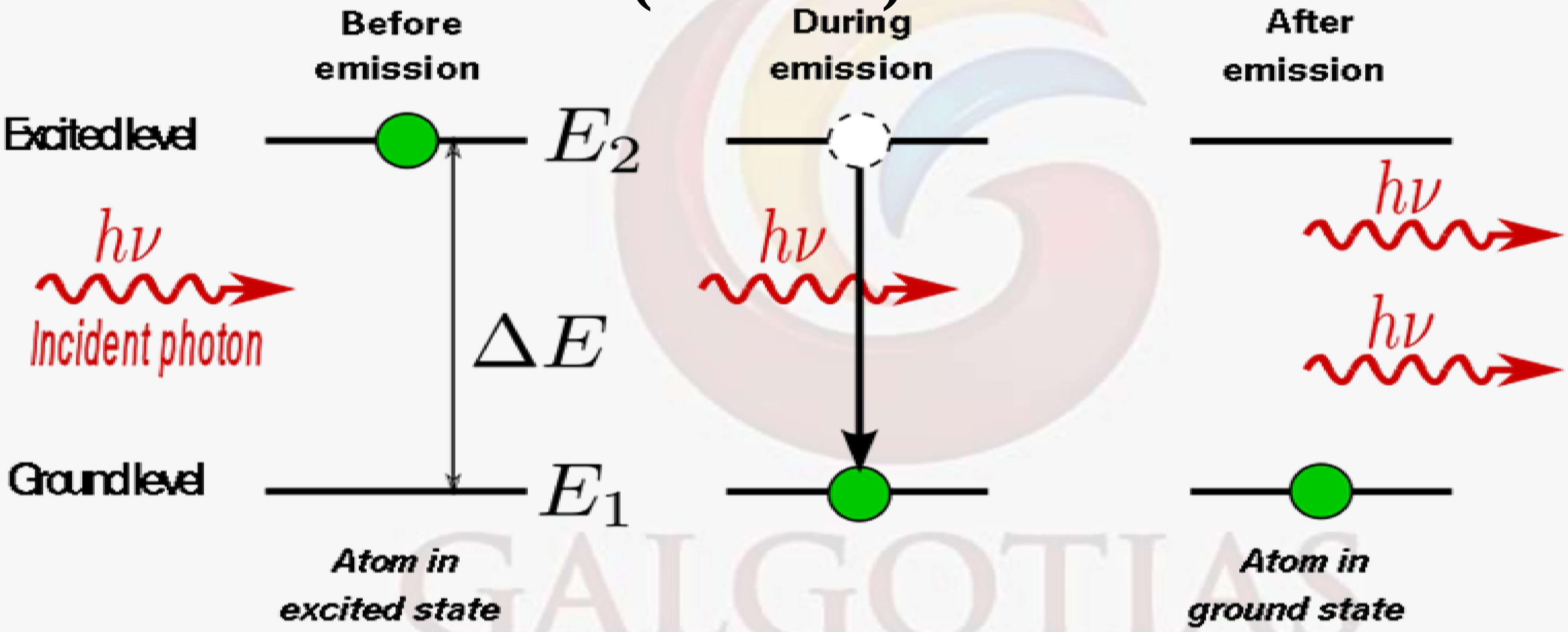


Fig.3 Stimulated emission of radiation

Stimulated (induced) emission of radiation



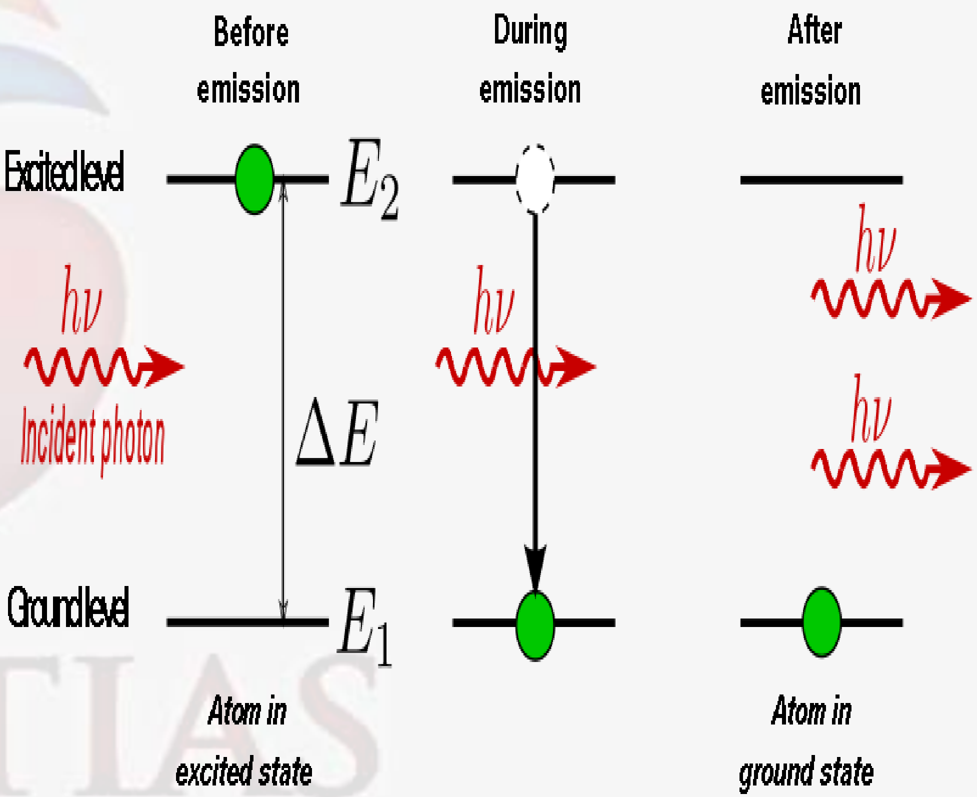
$$E_2 - E_1 = \Delta E = h\nu$$

Spontaneous Emission	Stimulated Emission
1) Spontaneous emission is a result of the transition of an atom from the excited state to the lower energy state which happens due natural tendency of the atom to attain minimum energy.	1) Stimulated emission of radiation is the process in which photons are used to stimulate atom in excited state to fall down to lower energy state.
2) No external agent is involved.	2) Photons need to be incident as stimuli.
3) Results in ordinary light.	3) Can be utilized to get Laser beam.
4) Light obtained is not coherent.	4) Coherent light can be obtained.

Einstein Coefficients:

Suppose the rate of transition between the two energy state 1 and 2 having energies E_1 and E_2. The probable rate of occurrence of absorption transition 1→2 depends upon the properties of states 1 and 2. This is proportional to the energy density u(υ) of the radiation of frequency υ incident on the atom. Energy density is defined as radiant energy per unit volume in the frequency interval υ and υ+ dυ. Therefore, probable rate of occurrence of absorption transition is

$$P_{12} = B_{12}u(\upsilon)$$



$$E_2 - E_1 = \Delta E = h\nu$$

Einstein Coefficients

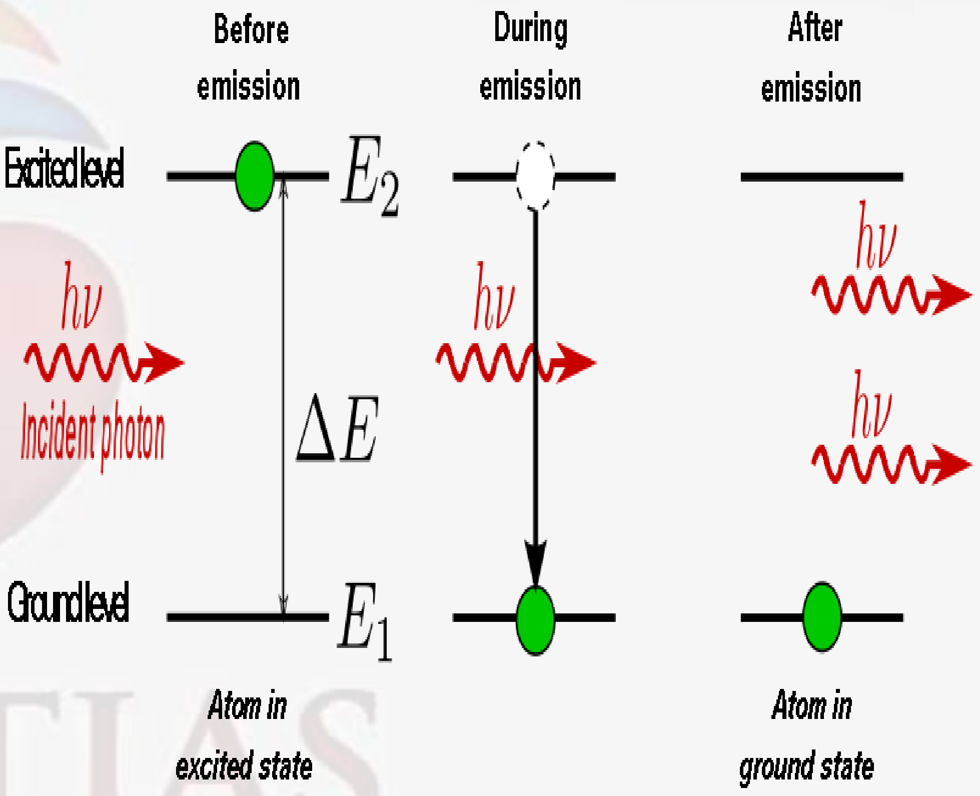
Here $\mathbf{B_{12}}$ = proportionality constant known as Einstein's coefficient of absorption radiation.

The probability of spontaneous emission 2→1 is determined only by the properties of states 2 and 1. This is denoted by A_{21} and is known as Einstein's coefficient of spontaneous emission of radiation. This is independent of energy density u(υ).

The probability of stimulated emission transition 2→1 is proportional to energy density u(υ) of the stimulating radiation and is given by $P'_{21} = B_{21}u(\upsilon)$

Here B_{21} is Einstein's coefficient of stimulated emission of radiation. Total probability for an atom in state 2 to 1 is

$$P_{21} = A_{21} + B_{21}u(\upsilon)$$



$$E_2 - E_1 = \Delta E = h\nu$$

Relation between Einstein's coefficients

Let us consider an assembly of atoms in thermal equilibrium at temperature T with radiation of frequency υ and υ+dυ and energy density u(υ). Let N_1 and N_2 be the number of atoms in lower energy state 1 and higher energy state 2 respectively. The number of atoms in state 1 that absorbs a photon and rise to state 2 per unit time is given by

$$N_1 P_{12} = N_1 B_{12} u(\upsilon)$$

The number of atom in state 2 that drop to state 1, either by spontaneous emission or by stimulated emission is given by

$$N_2 P_{21} = N_2 [A_{21} + B_{21} u(\upsilon)]$$

Relation between Einstein's coefficients

Under the condition of equilibrium, the number of atoms absorbing radiation per unit time is equal to the number of emitting radiation per unit time, hence

$$N_1 P_{12} = N_2 P_{21}$$

$$N_1 B_{12} u(v) = N_2 [A_{21} + B_{21} u(v)]$$

$$[N_1 B_{12} - N_2 B_{21}] u(v) = N_2 A_{21}$$

$$u(v) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{A_{21}}{B_{21}} \times \frac{1}{\frac{N_1}{N_2}\left(\frac{B_{12}}{B_{21}}\right) - 1}$$

Relation between Einstein's coefficients

Thermodynamically it was proved by Einstein that the probability of stimulated absorption is equal to the probability of stimulated emission i.e.

$B_{12}=B_{21}$

Hence

$$u(v)=\frac{A_{21}}{B_{21}}\times\frac{1}{\frac{N_1}{N_2}-1}$$

Now according to Boltzmann distribution law, the ratio of N_1 and N_2 is given by

$$\frac{N_1}{N_2}=\exp\left(\frac{E_2-E_1}{kT}\right)=\exp\left(\frac{hv}{kT}\right)$$

Here k is Boltzmann constant

Relation between Einstein's coefficients

$$u(v) = \frac{A_{21}}{B_{21}} \times \frac{1}{\exp\left(\frac{hv}{kT}\right) - 1}$$

According to Planck's radiation law, the energy density of radiation is given by

$$u(v) = \frac{8\pi h v^3}{c^3} \times \frac{1}{\exp\left(\frac{hv}{kT}\right) - 1}$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{c^3}$$

It shows the ratio of Einstein's coefficients of spontaneous emission to stimulated emission is directly proportional to the cube of frequency. This shows the probability of spontaneous emission increases rapidly with the increase of energy difference between two states.

Condition for light amplification

At the thermal equilibrium

$$\frac{stimulated\ transition}{spon\tan e\,ous\ transition} = \frac{B_{21}N_2u(v)}{A_{21}N_2} = \frac{B_{21}}{A_{21}}u(v)$$

$$\frac{stimulated\ transition}{absorption\ transition} = \frac{B_{21}N_2u(v)}{B_{12}N_1u(v)} = \frac{N_2}{N_1}$$

since $B_{12} = B_{21}$

it is concluded that in order to enhance the number of stimulated transitions the radiation density is to be made larger.

The stimulated emission will be larger that absorption only when $N_2>N_1$, otherwise $N_2<N_1$ absorption phenomenon dominates.

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THANK YOU